replace differentiated cells lost due to injury and disease. This involves therapeutic cloning. Parkinson's disease and Alzheimer's disease are caused by loss of brain cells, and it is hoped that implanted stem cells could replace many of these lost brain cells thus relieving the disease symptoms. Certain forms of diabetes deplete the pancreas of essential cells and it is hoped that a stem cell implant in this organ could have positive effects. As most of the research at present is occurring in mice, it is likely to be quite a time before this treatment approach becomes possible in humans.

However, there is a type of stem cell treatment that has been proceeding successfully in humans for many years. Besides embryonic or pluripotent stem cells, there are tissue-specific stem cells. These stem cells reside in certain tissue types and can only produce new cells of that particular tissue. For example, blood stem cells have been routinely introduced into humans to replace the damaged bone marrow of some leukaemia patients.

There are important ethical issues involved in stem cell research. Especially controversial is the use of embryonic or pluripotent stem cells. This is because these cells come from embryos often obtained from laboratories carrying out in-vitro fertilization (IVF). To gather these cells involves death of the embryo and opponents argue that this represents the taking of a human life. On the other hand, it is argued that this research could result in the significant reduction of human suffering and is, therefore, totally acceptable.

Internationally, there has been much sharing of data involving stem cell research. Many nations have banned or limited research in this area due to local, cultural and religious traditions.

Where do you stand in the debate about the nature of stem cell research? How do you feel about the source of pluripotent stem cells?

How the scientific community conveys information concerning its research to wider society is very important. This information must be accurate, complete and understandable so that society can make informed decisions as to the appropriateness of the research. For example, in 2005, stem cells successfully helped to restore the lost insulation of nerve cells in rats thus resulting in greater mobility of the animals.

But there is a need to balance the very great opportunities of this type of research with the potential risks. For example, there is recent evidence that some types of cancer may be caused by stem cells undergoing a malignant transformation. This shows possible risk in the implantation of stem cells.

Exercises

1. How would the excretion of metabolic wastes from cells be related to the concept of surface area to volume ratio?
2. Name two disadvantages of using an electron microscope.
3. How does specialization in muscle and nerve cells affect their ability to reproduce?
4. What would prevent stem cells from other species being successful in humans?

2.2 Prokaryotic cells

Assessment statements

2.2.1 Draw and label a diagram of the ultrastructure of *Escherichia coli* (*E. coli*) as an example of a prokaryote.

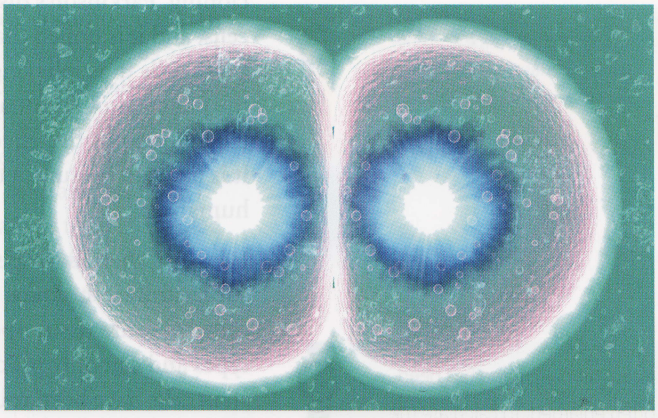
2.2.2 Annotate the diagram with the functions of each named structure.

2.2.3 Identify structures from 2.2.1 in electron micrographs of *E. coli*.

2.2.4 State that prokaryotic cells divide by binary fission.

Cell reproduction and differentiation

One of the functions that many cells retain is the ability to reproduce themselves. In multicellular organisms, this allows the possibility of growth. It also allows for the replacement of damaged or dead cells.



This is a computer artwork of an egg cell fertilized during in vitro fertilization and now undergoing the first cell division.

Multicellular organisms like ourselves usually start out as a single cell after some type of sexual reproduction. This single cell has the ability to reproduce at a very rapid rate, and the resulting cells then go through a differentiation process to produce all the required cell types that are necessary for the well-being of the organism. The number of different cell types from the one original cell may indeed be staggering. This differentiation process is the result of the expression of certain specific genes but not others. Genes, segments of DNA on a chromosome, allow for the production of all the different cells in the organism. Therefore, each cell contains all the genetic information for the production of the complete organism. However, each cell becomes a specific type of cell dependent on which DNA segment becomes active.

Some cells have a greatly, or even completely, diminished ability to reproduce once they become specialized. Nerve and muscle cells are prime examples of this type of cell. Other cells, such as epithelial cells like skin, retain the ability to rapidly reproduce throughout their life. The offspring of these rapidly reproducing cells then differentiate into the same cell type as the parent.

Stem cells

There are populations of cells within organisms that retain their ability to divide and differentiate into various cell types. These cells are called stem cells.

Plants contain such cells in regions of meristematic tissue. Meristematic areas occur near root and stem tips and are composed of rapidly reproducing cells that produce new cells capable of becoming various types of tissue within the root or stem. Gardeners take advantage of these cells when they take cuttings from stems or roots and use them to produce new plants.

In the early 1980s, scientists found pluripotent or embryonic stem cells in mice. These stem cells retain the ability to form any type of cell in an organism and can even form a complete organism.

When stem cells divide to form a specific type of tissue, they also produce some cells that remain as stem cells. This allows for the continual production of a particular type of tissue. Medical experts immediately noted the possibilities of such cells in treating certain human diseases. But a problem discovered early in the research was that stem cells cannot be distinguished by their appearance. They can only be isolated from other cells on the basis of their behaviour.

Stem cell research and treatments

Some of the most promising research recently has been directed towards growing large numbers of embryonic stem cells in culture so that they could be used to

Most cells are up to 100 micrometres; organelles are up to 10 micrometres.

Bacteria are up to 1 micrometre.

Viruses are up to 100 nanometres.

Membranes are 10 nanometres thick, and molecules are near 1 nanometre.

All of these objects are three-dimensional.

Light microscopes use light, which passes through the living or dead specimen, to form an image. Stains may be used to improve viewing of parts. Electron microscopes provide us with the greatest magnification (over 100 000×) and resolution. These use electrons passing through a specimen to form an image. It is hard to understand or visualize very small sizes, so it is important to appreciate relative size. Cells are relatively large, and then in decreasing size order are:

- organelles;
- bacteria;
- viruses;
- membranes;
- molecules.

Drawings or photographs are often enlarged. To calculate the magnification, you need this formula:

- magnification = size of image divided by size of specimen.

If you want to calculate the actual size of a specimen seen with a microscope, you need to know the diameter of the microscope's field of vision. This may be calculated with a special micrometer or with a simple ruler on a light microscope. The size of the specimen can then be calculated in the field.

Scale bars are often used with a micrograph or drawing so that actual size can be determined.

Limiting cell size

So, the cell is a small object. You may wonder why cells do not grow to larger sizes, especially since growth is one of the functions of life. There is a factor called the surface area to volume ratio that effectively limits the size of cells. In the cell, the rate of heat and waste production and rate of resource consumption are functions of (depend on) its volume. Most of the chemical reactions occur in the interior of the cell and its size affects the rate of these reactions. The surface of the cell, the membrane, controls what materials move in and out of the cell. Cells with more surface area per unit volume are able to move more materials in and out of the cell, for each unit volume of the cell.

As the width of an object such as a cell increases, the surface area also increases but at a much slower rate than the volume. This is shown by the following table in which you can see that the volume increases by a factor calculated by cubing the radius; at the same time, the surface area increases by a factor calculated by squaring the radius.

Sphere formulas:

- surface area = (four)(pi)(radius squared) = $4\pi r^2$
- volume = (four-thirds)(pi)(radius cubed) = $\frac{4}{3}\pi r^3$

Cell radius (r)	0.25 units	0.5 units	1.25 units
Surface area	0.79 units	3.14 units	7.07 units
Volume	0.06 units	0.52 units	1.77 units
Surface area : volume	13.17 : 1	6.04 : 1	3.99 : 1

This means that a large cell has relatively less surface area to bring in needed materials and to rid the cell of waste, than a small cell. Because of this, cells are limited as to the size they can attain and still be able to carry out the functions of life. Thus, large animals do not have larger cells, they have more cells.
Cells that are larger in size have modifications that allow them to function efficiently. This is accomplished by shape changes such as from spherical to long and thin. Also, some larger cells have infoldings or outfoldings to increase their surface relative to their volume.

Cell theory

It has taken several hundred years of research to formulate modern cell theory. Many scientists have contributed to developing the three main principles of this theory. These are:

- all organisms are composed of one or more cells;
- cells are the smallest units of life;
- all cells come from pre-existing cells.

This theory has amassed tremendous credibility, largely through use of the microscope – an important tool. Robert Hooke first described cells in 1665 while observing cork with a microscope he built himself. A few years later, Antonie van Leeuwenhoek observed the first living cells and referred to them as 'animalcules', meaning little animals. In 1838, botanist Mathias Schleiden stated that plants are made of 'independent, separate beings' called cells. One year later, the zoologist Theodor Schwann made a similar statement about animals.

The second principle continues to gain support today, as we have not been able to find any living entity that is not made of at least one cell.

Some very famous scientists, such as Louis Pasteur in the 1860s, have performed experiments to support the last principle. After sterilizing chicken broth by boiling, Pasteur showed that living organisms would not 'spontaneously' reappear. Only after exposure to pre-existing cells was life able to re-establish itself in the sterilized chicken broth.

Theories are developed after the accumulation of much data. Sometimes, theories are completely abandoned because of conflicting evidence.

Viruses are not considered to be living. They can not carry out the functions of life on their own. However, they do utilize cells to perpetuate themselves.

Functions of life

All organisms exist in either a unicellular or a multicellular form. And all organisms carry out all the functions of life. These functions include:

- metabolism;
- growth;
- reproduction;
- response;
- homeostasis;
- nutrition.

The functions of life are manifested in different ways in the various types of organism, but all life forms maintain the same general functions.

You may see different terms for these functions in other sources.

All these functions are tied together to produce a functioning living unit.

- Metabolism includes all the chemical reactions that occur within an organism.
- Growth may be limited but is always evident in one way or another.
- Reproduction involves hereditary molecules that can be passed to offspring.
- Response to the environment is imperative to the survival of the organism.
- Homeostasis refers to maintaining a constant internal environment. Examples of constant internal environments may involve temperature and acid–base levels.
- Nutrition is all about providing a source of compounds with many chemical bonds which can be broken to provide the organism with the energy and the nutrients necessary to maintain life.

Cells and sizes

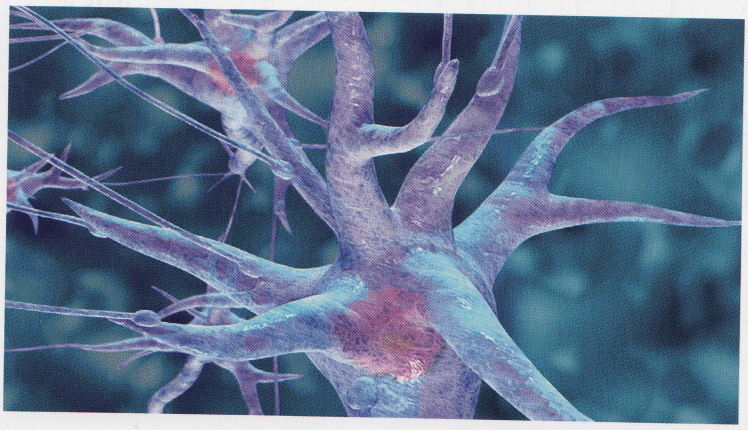
Cells are made up of a number of different subunits. These subunits are often of a particular size, but all are microscopically small. In most cases, microscopes with high magnification and resolution are needed to observe cells and especially their subunits. Resolution refers to the clarity of a viewed object.

2 Cells

Introduction

Whether organisms are extremely small or extremely large, it is imperative to understand their smallest functional units. These units are known as cells. Organisms range in size from a single cell to thousands of cells. To better understand plants and all the organisms around us, we must study their cells.

Look at the picture. Human nerve cells (neurones) are essential to our lives. Because of these cells, we are able to acknowledge and respond to our surroundings. Neurones are usually very efficient but sometimes things go wrong. Will a greater understanding and better treatment of conditions such as depression result from an improved comprehension of how these cells function?



This is an artist's impression of human nerve cells.

2.1 Cell theory

Assessment statements

- 2.1.1 Outline the cell theory.
- 2.1.2 Discuss the evidence for the cell theory.
- 2.1.3 State that unicellular organisms carry out all the functions of life.
- 2.1.4 Compare the relative sizes of molecules, cell membrane thickness, viruses, bacteria, organelles and cells, using the appropriate SI unit.
- 2.1.5 Calculate the linear magnification of drawings and the actual size of specimens in images of known magnification.
- 2.1.6 Explain the importance of the surface area to volume ratio as a factor limiting cell size.
- 2.1.7 State that multicellular organisms show emergent properties.
- 2.1.8 Explain that cells in multicellular organisms differentiate to carry out specialized functions by expressing some of their genes but not others.
- 2.1.9 State that stem cells retain the capacity to divide and have the ability to differentiate along different pathways.
- 2.1.10 Outline one therapeutic use of stem cells.